Using ECCO Data to Validate SWOT Calibration

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- SWOT is a NASA decadal review mission that will provide a quantum improvement for oceanography and hydrology

- Oceanography: First global determination of the ocean circulation, kinetic energy and dissipation at high resolution

- Hydrology: First global inventory of fresh water storage and its change on a global basis

TABLE ES.2 Launch, orbit, and instrument specifications for the recommended NASA missions. Shade colors denote mission cost categories as estimated by the NRC ESAS committee. Pink, green, and blue shadings represent large ($600 million to $900), medium ($300 million to $600 million), and small (<$300 million) missions, respectively. Missions are listed in order of ascending cost within each launch timeframe. Detailed descriptions of the missions are given in Part II, and Part III provides the foundation for selection.

| Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

[a] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high accuracy SST measurement.

# SWOT is endorsed by the U.S. National Academy of Sciences

- 100+ submitted mission ideas
  - SWOT is a combination of the WatER and Hydrosphere Mapper missions submitted to the NRC
- 115 people involved
  - committee members and referees
- 17 missions selected

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www.nap.edu/catalog/11820.html

SWOT

- Conventional Altimetry
  - Despite a few altimeters operating simultaneously, 200 to 300 km gaps prevent sampling
  - Along track resolution is much greater than across track
  - Coastal zones essentially not measured
- Oceanography and Applications Issues
  - Ocean currents contain 90% of kinetic energy, but are ~10 km scale in cross-stream direction, e.g. Gulf Stream, Kuroshio
    - What are the energy dissipation, ocean circulation, and climate implications?
  - Upwelling at coasts and cross-shelf transport are <10km scales
    - Implications on marine life, ecosystems, waste disposal, transportation
  - Hurricanes have complex spatial structure
    - Multiple altimeters allow 21% improvement in Hurricane Ivan 96 hour lead time forecast
    - Denser sampling required for forecasts
  - Ocean bathymetry can be mapped from slopes in the ocean water surface topography

$\delta h \sim 5$ cm
$\delta v \sim 50$ cm/s

< 10 km

T. Strub
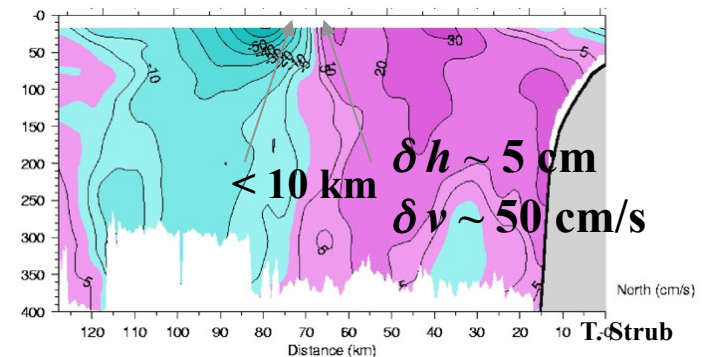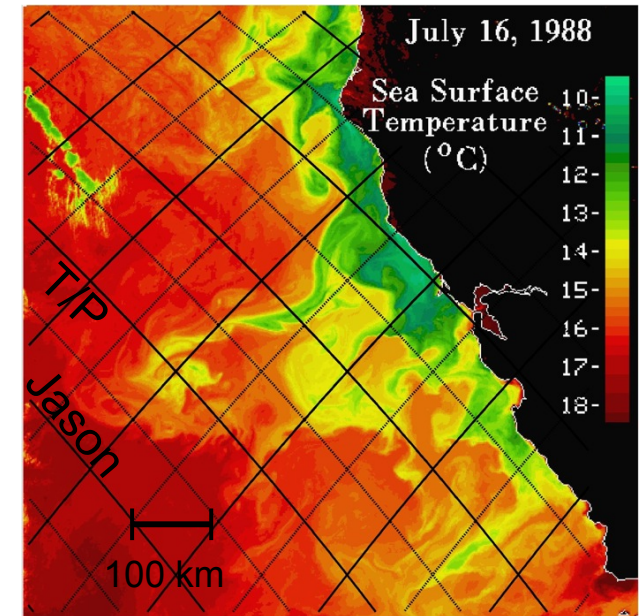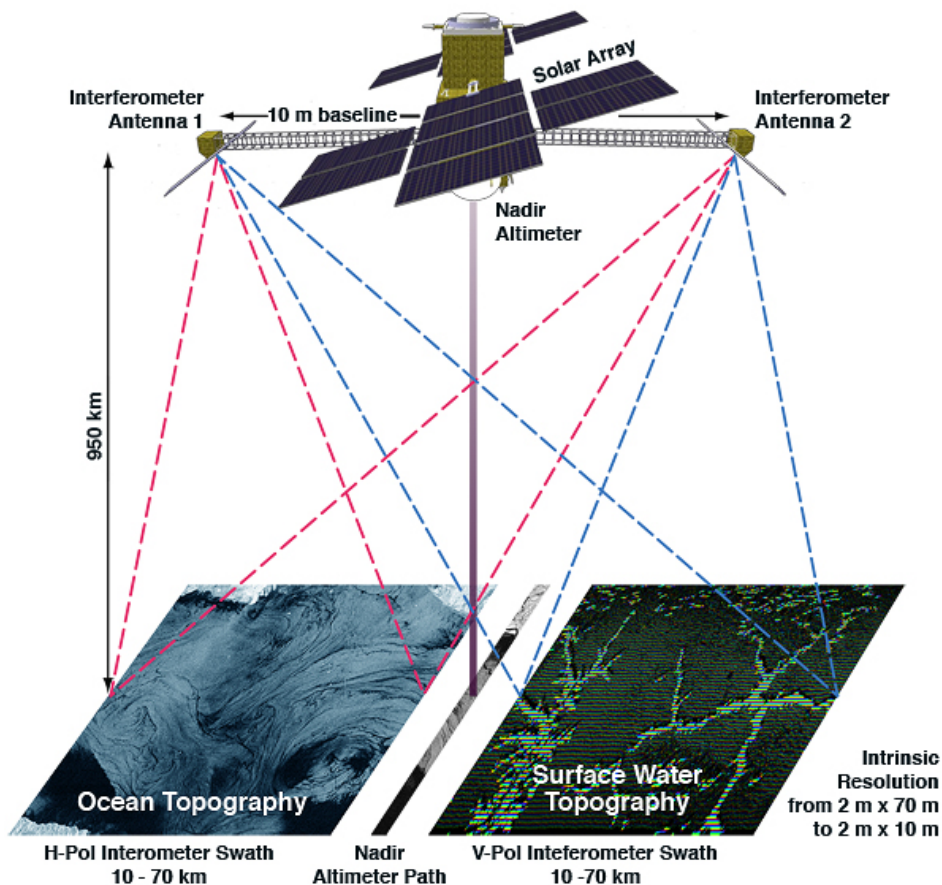
- Ka-band SAR interferometric system with 2 swaths, 60 km each (KaRIN)
  - WSOA and SRTM heritage
  - Produces heights and co-registered all-weather imagery required by both ocean and hydrology communities
- Conventional Jason-class altimeter for nadir coverage
- AMR-class radiometer (with possible high frequency band augmentation) to correct for wet-tropospheric delay
- GPS receiver for precision orbit determination
- No land data compression onboard (~50m resolution)
- Onboard data compression over the ocean (1km resolution)

SSH error spectral requirement (to resolve signals down to 10 km wavelength)

2.7.2.a [Requirement] The sea surface height error spectrum in the wavelength range smaller than 1,000 km shall not exceed the spectrum envelope given in the figure and the formula below.
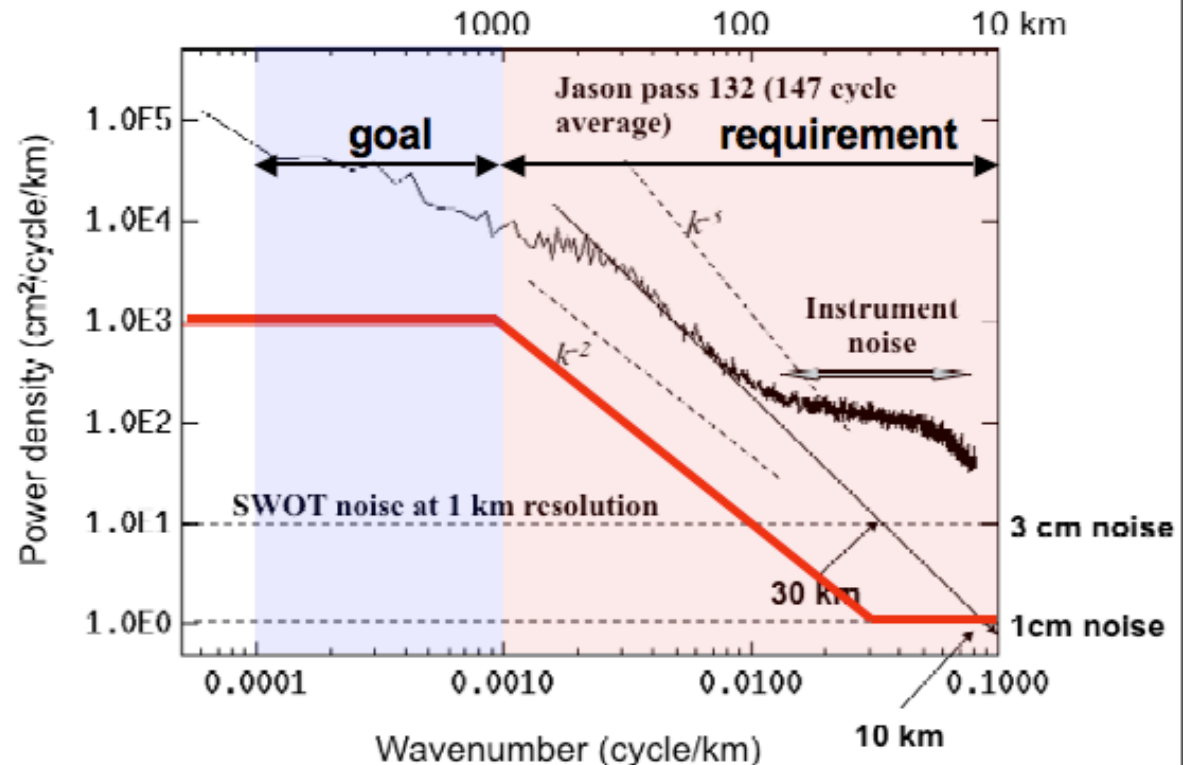
2.7.2.b **[Goal]** The sea surface height error spectrum in the wavelength range between 1,000 km and 10,000 km shall not exceed the spectrum envelope given in the figure and the formula below.

The SSH spectrum is defined such that the SSH error **variance** in the interval $[\boxtimes_{min}, \boxtimes_{max}]$ is:
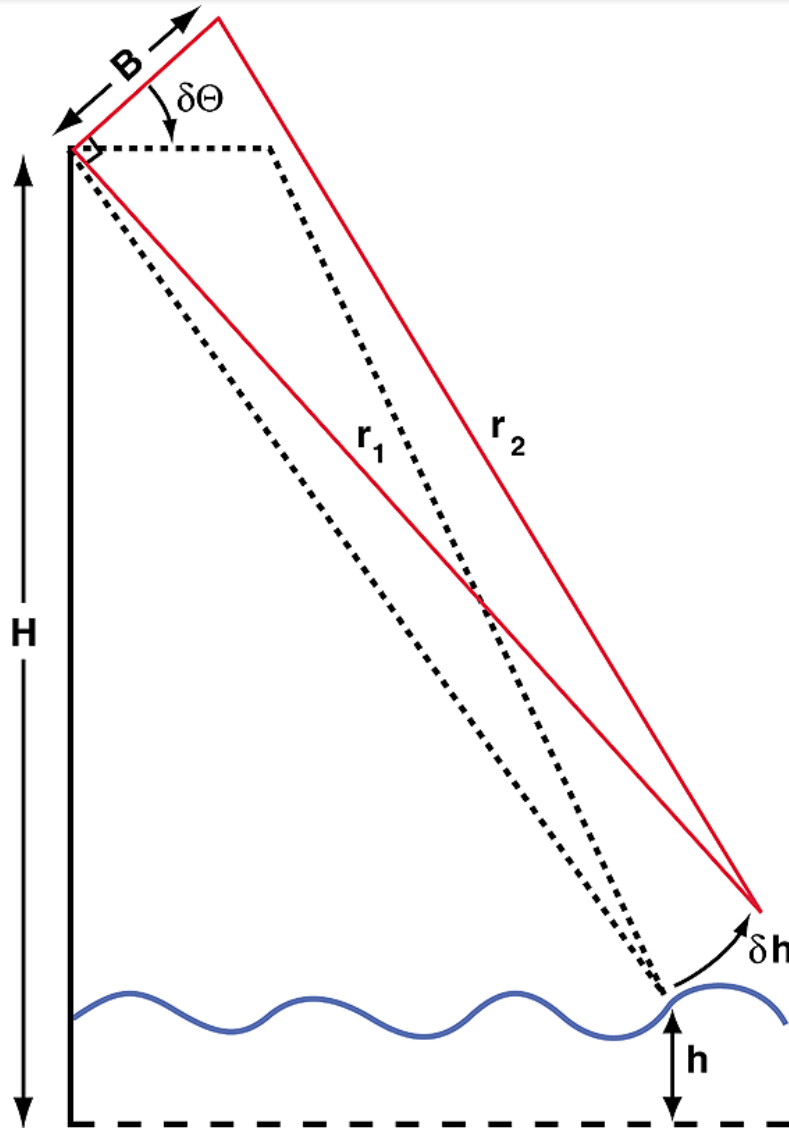
$$\left\langle (\delta h)^2 \right\rangle = \int_{1/\lambda_{max}}^{1/\lambda_{min}} E(f)df$$

And the SSH RMS error is:

$$\varepsilon_{ssh} = \sqrt{\left\langle (\delta h)^2 \right\rangle} = \sqrt{\int_{1/\lambda_{max}}^{1/\lambda_{min}} E(f)df}$$

$$E(f) = \begin{cases} 1000 \quad cm^2/(cycle/km) & , 1{,}000\ km < \lambda < 10{,}000\ km \\ 0.001\ f^2 \quad cm^2/(cycle/km) & , 31.62\ km < \lambda < 1{,}000\ km \\ 1 \quad cm^2/(cycle/km) & , 1\ km < \lambda < 31.62\ km \end{cases}$$

$$\delta h = r \sin \Theta \, \delta \Theta$$

• An error in the baseline roll angle tilts the surface by the same angle.

  • This is equivalent to introducing a constant geostrophic current in the along-track direction

• As an order of magnitude, a 0.1arcsec roll error results in a 3.4cm height error at 70km from the nadir point

• Roll knowledge error sources:

  • Errors in spacecraft roll estimate

  • Mechanical distortion of the baseline (can be made negligible if the baseline is rigid enough)
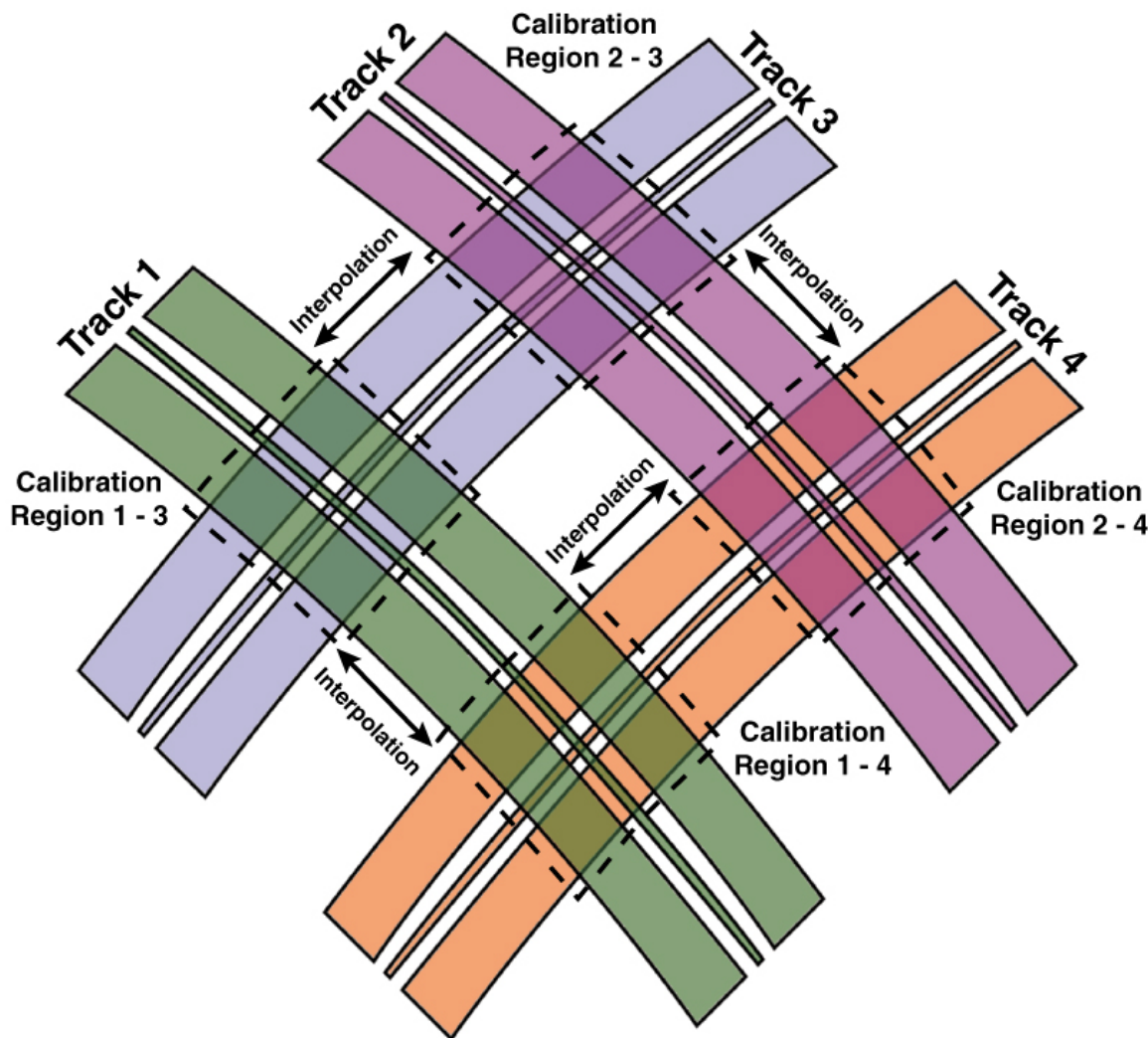
- **Roll errors must be removed by calibration**

- Assume the ocean does not change significantly between crossover visits

- For each cross-over, estimate the baseline roll and roll rate for each of the passes using only interferometer-interferometer cross-over differences, which define an over-constrained linear system.

- Interpolate along-track baseline parameters between calibration regions by optimal interpolation, assuming roll error correlation function is known

- Issues relative to previous WSOA studies
  - The repeat time has increased from 10 days to 22 days. The revisit time between cross-overs has increased
  - Change in orbit inclination relative to Jason altimeter means that cross-over geometry has changed
  - To capture these changes, a realistic representation of the ocean mesoscale is required
    - ECCO-2 provides a unique capability for representing the ocean mesoscale realistically.
  - Used 30 days of ECCO-2 data to assess the validity of the cross-calibration process
  - The initial assessment was sufficient to assess the SWOT feasibility. However, getting global statistics requires a longer global data set.
  - A gobal simulation of SWOT data products will be conducted using one year of ECCO-2 data (Thank you ECCO-2 community!)

SWOT

- Results show that changes in cross-over geometry have not affected the calibration accuracy

- Results also show that interferometer only calibration is sufficient for roll restitution

- Interferometer-Altimeter cross-calibration required for range calibration to altimeter global frame

Error represents swath average error

SWOT
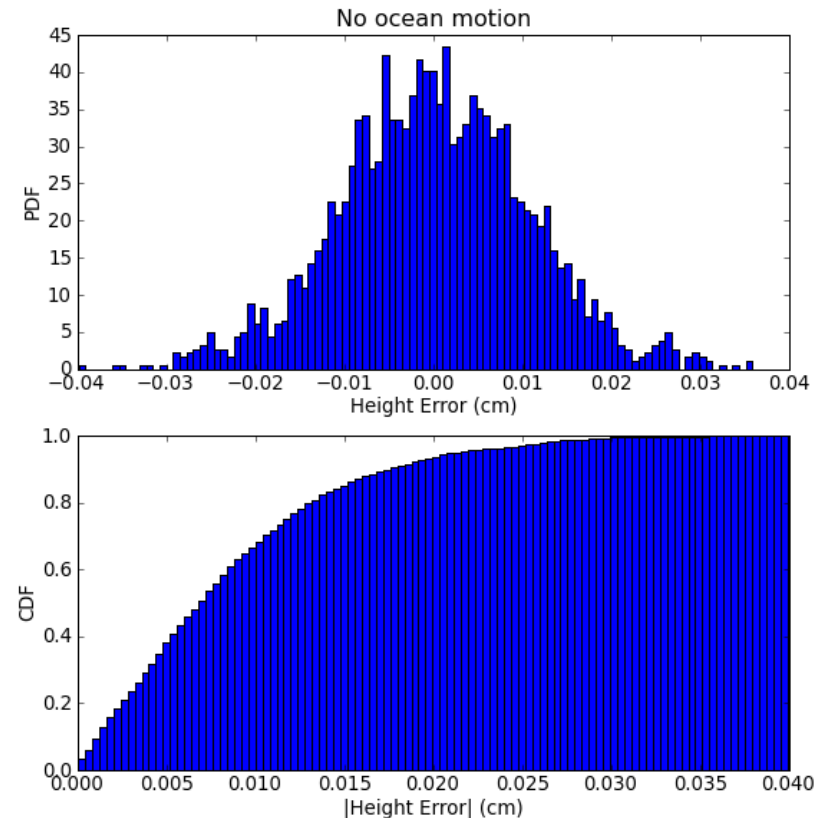
- Ocean motion between cross-over revisits is the dominant contributor to the roll calibration error budget

- In general, the calibration parameters are well behaved, but the distribution has large tails

- 68% error < 1.5 cm

- 80% error < 2.0 cm

- 90% error < 5.0 cm

Error represents swath average error

SWOT
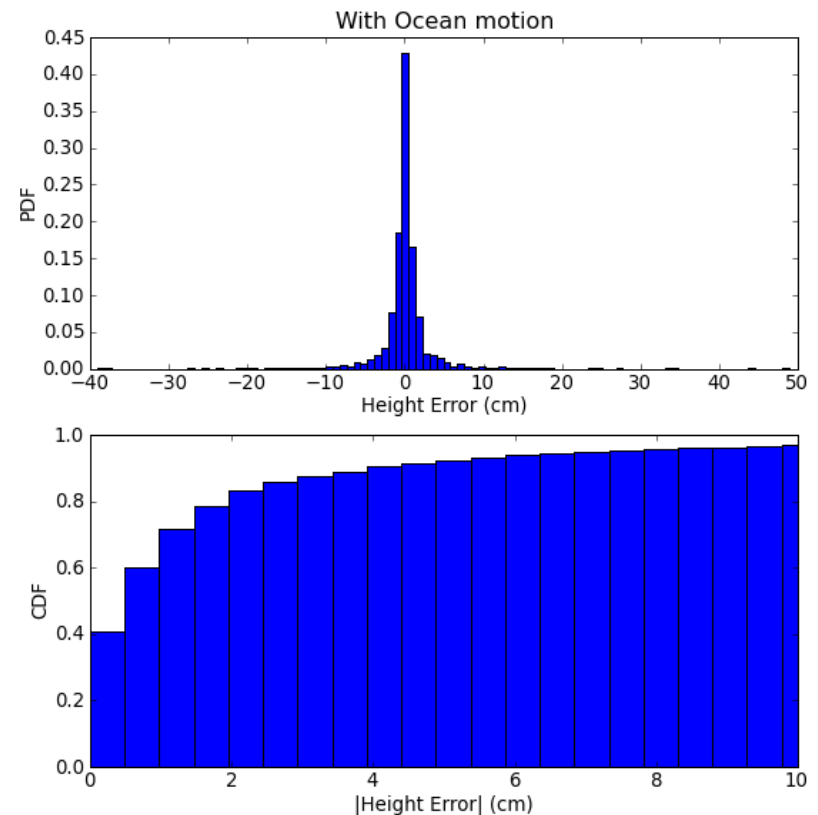
- The roll stability 1km-1000km (requirement) is not dependent on the cross-over calibration, but on platform stability

- Wavelengths longer than 1000km (goal) are dependent on the roll calibration

- Results of the simulation using ECCO-2 data show that the long-wavelength errors of SWOT can be calibrated with an accuracy consistent with nadir altimeter missions

- Results presented here are preliminary
    – Final results will use one year of ECCO-2 data

- Issues that need to be investigated:
    – Dropping cross-overs with long revisit times
    – Dropping cross-overs over regions of high mesoscale activity
    – Dropping estimates inconsistent with optimal interpolation

- Key issue in the mission design:
    – Correlation time for spacecraft roll